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ECEN350
Switched 12V Lab

<u>ECEN 350 – Switched 12 V Lab (50 points)</u>
(jas, Switched 12 V Lab.docx, 12/28/2024)

Note: You can work in pairs if desired on this lab, although no three person teams are allowed. Submit an electronic version of a lab report to receive credit for doing this lab. The goal of your **lab report is to provide sufficient documentation so that the lab can be repeated if necessary**. Therefore, simply add to this document to arrive at your lab report, as all the explanatory text, procedures, and Discussion and Conclusion questions contained in this document are required for a complete lab report. So, for your lab report, **add a cover page that includes name or names, class and name of the lab. Also add in your results, and answers to the Discussion and Conclusions questions to the existing lab document**. While you are to share all **Procedure** items with your lab partner if you worked in a pair, your **Discussion and Conclusions** section is to be uniquely yours and not a copy of your lab partners. See the grading rubric at the end of this document for more details.

Purpose: To build and test a circuit that enables a microcontroller control port to switch on and off 12 V powered devices. The switched 12 V output circuit utilizes a P-Channel MOSFET for the switch and incorporates a current limit to protect the MOSFET switch from being damaged by accidental load faults, such as unintended shorting of the output.

Parts and Equipment:

1 - VirtualBench Measurement System and Computer
1 – Breadboard
1 – IRF9540N P-Channel MOSFET
1 – 2N3904 npn transistor
1 – 2N3906 pnp transistor
1 – P6KE24A TVS Diode
3 – 1 kΩ resistors
1 – 5.1 kΩ resistors
1 – 10 kΩ resistors
1 – 51 kΩ resistors
1 – 100 kΩ resistors
1 – 4.3 Ω resistor
2 – 100 Ω 1 W power resistor
1 – 33 Ω 2 W power resistor
3 – 22 Ω 2 W power resistors
1 – 12 V DC Fan. (Note: There are not enough fans for each group, so those available need to be shared).

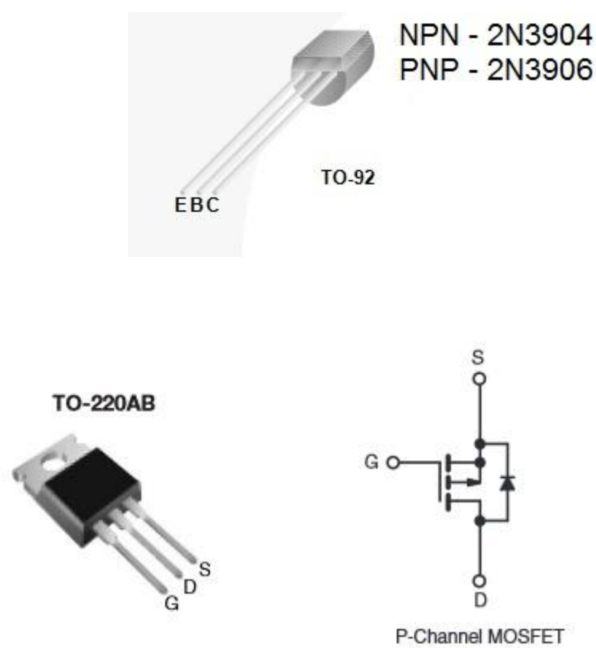

Figure 1: Pin Definitions of transistors used in the Switched 12 V lab.

The circuit to be implemented in this lab is illustrated below in **Figure 2**. Referring to **Figure 2**, p-channel MOSFET (M1) is used to switch the 12 V on and off between V_{supply} and the SW12V output. Transistor Q1 is used to turn on and off the P-Channel MOSFET (M1), by means of the $V_{on/off}$ supply, which could be implemented with a 0 to 3.3 V output available from a microcontroller digital I/O. The $V_{on/off}$ supply is to be implemented with the VirtualBench adjustable +6 V supply set to +3.3 V for the on condition of the switched 12 V circuit. Because of the 10 kΩ pull-down resistor R1, simply disconnecting the $V_{on/off}$ supply from the breadboard will turn off the switched 12 V circuit, as will setting the $V_{on/off}$ supply to 0.00 V. The V_{supply} is to be implemented with the VirtualBench adjustable +25 V supply set to +12 V. Referring to **Figure 2**, with $V_{on/off} = 3.3$ V, transistor Q1 is turned on, pulling the node labeled V_a to approximately 1.0 V, resulting in the gate terminal of transistor M1 also equal to approximately 1.0 V. MOSFET transistors exhibit extremely high input resistance/impedance at the gate terminal, meaning that no dc current flows through protection resistor R6 into the gate terminal of the MOSFET. For this p-channel MOSFET, a gate voltage of 1 V and a source voltage of 12 V results in a source-to-gate voltage of approximately 11 V, which turns on transistor M1 resulting in SW12V ≈ 12 V. With $V_{on/off} = 0$ V, Q1 and M1 are both turned off and SW12V = 0 V. Diode D1 is a Transient Voltage Suppressor (TVS) diode, used to clamp excessive voltages that occur when the fan motor current is abruptly changed. TVS diodes are essentially rugged Zener diodes commonly used for circuit protection.

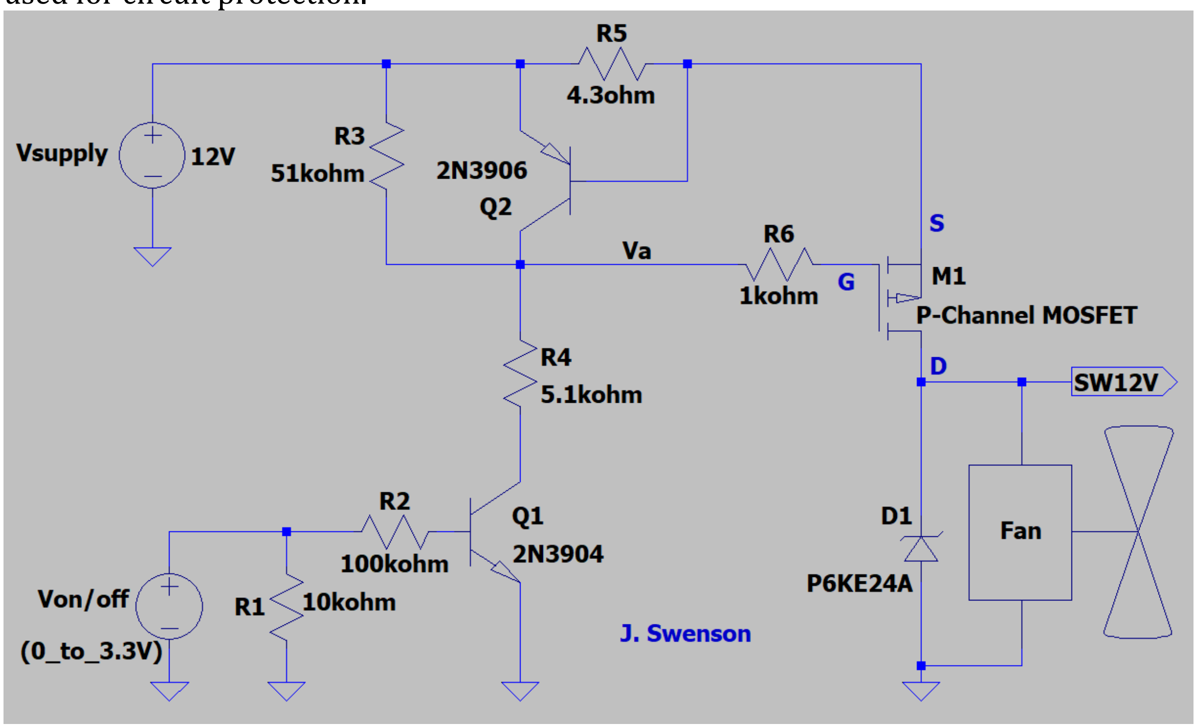

Figure 2: Switched 12 V Circuit.

P-Channel MOSFET M1 is essentially a voltage-controlled switch, with the source-to-gate voltage being the controlling voltage. For source-to-gate voltages greater than 6 V, p-channel MOSFET transistor M1 is fully turned on, i.e., a closed switch, with an on-resistance $< 0.25\ \Omega$. For source-to-gate voltages less than 2.5 V, enhancement mode MOSFET M1 is turned off, i.e., an open switch, and SW12V = 0 V. The pnp current-limit transistor Q2 starts to turn on, i.e., conduct non-negligible collector current, for a voltage across R5 of approximately 0.66 V, which is a more accurate approximation for this circuit than the 0.7 V turn on voltage approximation often used for hand calculations. As a result, for a load current sufficient to induce a 0.66 V drop across resistor R5, pnp transistor Q2 turns on which causes the voltage V_a to increase, which in turn increases the source-to-drain resistance of MOSFET M1. Consequently, the maximum load current provided by the switched 12 circuit is approximately $(0.66\text{ V})/(4.3\ \Omega) = 154$ mA, by means of the well-defined V_{BE} turn-on voltage of a bipolar junction transistor.

Procedure:

1. Breadboard the Switched 12 V Circuit of **Figure 2.** The pre-made jumper wire pins can be directly inserted into the 2-pin connector associated with the 12 V DC fans
2. With a 12 V DC Fan as a load, verify the on-off functionality of the switched 12 V output circuit and then complete **Table 1** below, using three significant figures for the measured output voltage. Be sure to include units for V_O, either by adding them to the column label or to each table entry. (4 points.)

Table 1: Switched 12 V Circuit Functionality.

$V_{on/off}$	SW12V	Fan State (On/Off)
0.00 V	0 V	Off
3.30 V	11.79 V	On

3. Next remove the 12 V DC fan and connect 1 kΩ resistor R_L from SW12V to Ground. Set $V_{on/off} = 3.30$ V to enable the switched 12 V output. Then characterize the output voltage versus output current of the Switched 12 V Circuit utilizing several different values for load resistor R_L and measuring the resulting output voltage and V_a voltage, using at least three significant figures. **Calculate the resulting load current or each of the various R_L values of Table 2 as $I_L = SW12V/R_L$. This Ohm's Law approach to determine the load current is preferred over measuring the current with a series ammeter, as the ammeter adds an additional series resistance.** Be sure to include units in your **Table 2** data, either by adding them to the column labels or to each value. (15 points.)

It is recommended that you disable your switched 12 V circuit simply by disconnecting the $V_{on/off}$ supply from your breadboard when you are changing out load resistor values, providing for safety along with allowing the p-channel MOSFET to cool off between measurements. Be cautious as the resistors and p-channel MOSFET will get hot to touch for load resistor values less than 500 Ω when completing **Table 2**.

Standard available resistors are only rated for 0.25 W, which is exceeded for a 21 mA load current from a 12 V supply. Power resistors (≥ 0.5 W) of value 100 Ω, 33 Ω, 22 Ω and 4.3 Ω are available in the STC 215 parts bins to aid in this output voltage versus load current characterization. Do not try and insert the leads of 33 Ω and 22 Ω power resistors into the breadboard holes, as these leads are too large. Instead use either alligator clip test leads or strip available telephone solid conductor insulated hook-up wire back an inch or more to connect to the 33 Ω and 22 Ω power resistors. Also, do not bend or twist these large leads together to connect them as they are then difficult to use again. Instead, separate Alligator Clips can be used to connect the large diameter lead power resistors in series, as shown below in **Figure 3**. Please straighten any leads that have already been bent or twisted together.

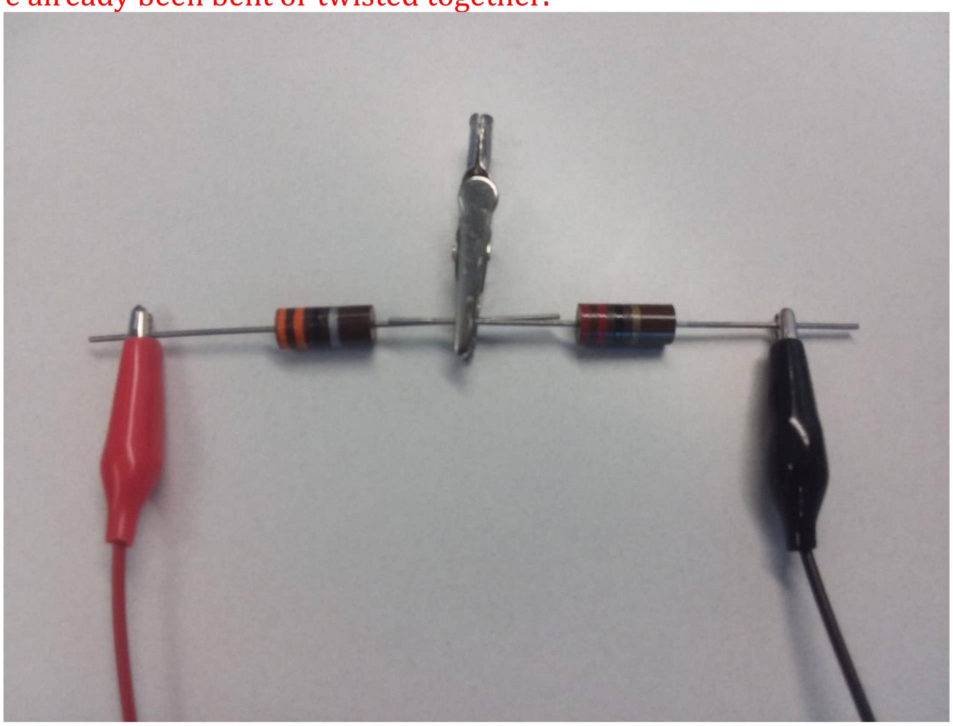

Figure 3: Illustration of Connecting a 33 Ω Power Resistor in Series with a 22 Ω Power Resistor to provide a 55 Ω Load.

Table 2: Measured Data for 12 V Output with V_{BE} Current Limit.

R_L	SW12V	I_L	V_a
∞	12.0 V	0.00 A	2.05 V
1 kΩ	12.0 V	12.0 mA	1.99 V
(1 kΩ)∥(1 kΩ)	11.9 V	23.8 mA	1.92 V
Power Resistors: 100 Ω + 100 Ω = 200 Ω	11.7 V	58.5 mA	1.75 V
Power Resistor: 100 Ω	11.0 V	110 mA	1.06 V
Power Resistors: 33 Ω + 22 Ω + 22 Ω = 77 Ω	10.6 V	138 mA	1.39 V
Power Resistors: 22 Ω + 22 Ω + 22 Ω = 66 Ω	10.5 V	159 mA	6.60 V
Power Resistors: 33 Ω + 22 Ω = 55 Ω	8.95 V	163 mA	6.40 V
Power Resistors: 33 Ω	5.30 V	161 mA	6.65 V
22 Ω	3.56 V	162 mA	6.54 V

3. From your measured **Table 2** values, plot SW12V on the y-axis with I_L on the x-axis. Add axis labels of "Load Current (mA)" for the x-axis and "SW12V (V)" for the y-axis, along with a title of "Switched Output Voltage versus Load Current – your name/names" to your plot as shown below. Replace the following graph of SW12V versus I_L with your version, including a figure number and caption. (5 points.)

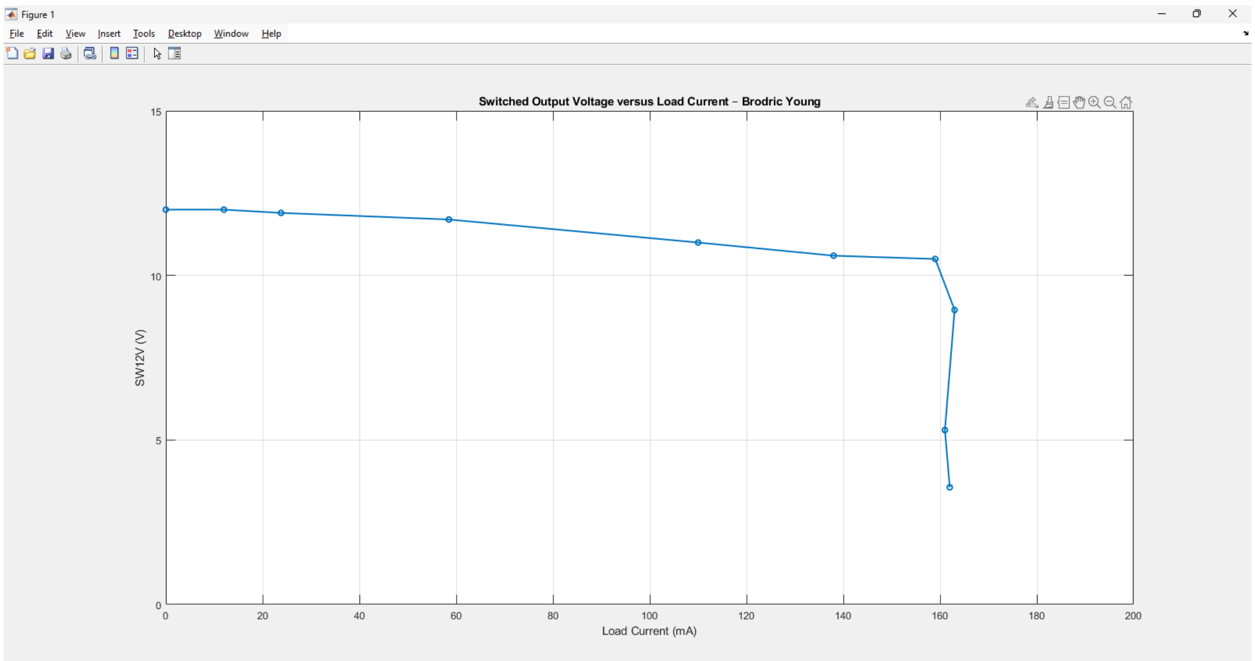

Figure 4: Output Voltage versus Load Current for the Switched 12 V Circuit.

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Discussion and Conclusions Questions: (For the following questions use your own words along with complete sentences. Points are to be deducted for AI generated answers.)

1. Explain how the V_{BE} current limit implemented in this lab functions, noting from your **Table 2** data that the voltage V_a dramatically increases at the onset of current limit operation. (8 points.)

   As R_{load} decreases, that increases the current to keep the same voltage. With an increased current, the voltage across R5, which is V_{BE}, increases as well which eventually gets larger than the 0.66 V needed to switch the transistor on and current will be taken from the load and sent through the two transistors and R4 to ground. The voltage at Va greatly increases when current in being limited because the transistor is on and sending current through which gets sent through R4 creating a voltage across it. R5 and R4 keep the voltage at gate of the MOSFET stable providing a constant current through it.

2. What value for resistor R5 would you choose to implement a current limit of approximately 200 mA? (2 points.)

$$\frac{0.66V}{200mA} = 3.3\Omega$$

3. The **Figure 5** schematic below is a circuit approximation to the switched 12 circuit with transistor M1 is turned on and without any current limiting circuitry. When powered with 12 V, transistor M1 has a source-to-gate voltage of approximately 11 V. From the IRF9640 enhancement mode p-channel MOSFET data sheet, the transistor has a 62.5 ˚C/W thermal resistance in the TO-220AB package used in the lab, and an $R_{DS(On)}$ of approximately 0.4 Ω with 12 V source-to-drain voltage and 11 V source-to-gate voltage. With the **Figure 2** circuit powered by a healthy 12 V lead-acid car battery (> 300 A), determine the theoretical increase in the junction temperature of MOSFET M1, i.e., ΔT $\Delta T = R_{\theta JA} P_D$, if the SW12V output were accidently shorted to ground. (Note: This should be a surprisingly large number.) Then briefly describe what you think would happen to the transistor during an accidental short. (4 Points. 3 points for calculation, 1 point for brief explanation.)

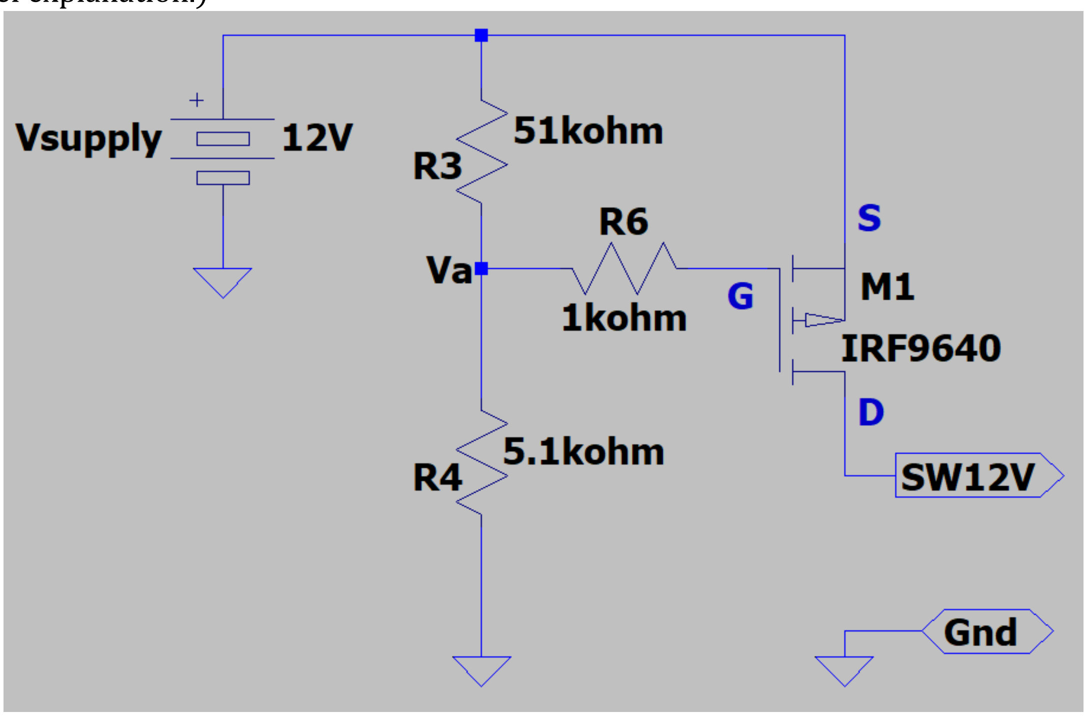

Figure 5: Switched 12 V Circuit with Switch M1 Turned On and No Current Limit.

$$\Delta T = \frac{62.5°C}{W} * \frac{12V^2}{0.4\Omega} = 22500°C$$

The MOSFET wouldn't stand a chance, it would burn out, melt, blow up, or something like that because that's way too much current for it to handle and therefore way too much heat. It would fail and be permanently damaged.

4. Other forms of overcurrent protection besides the V_{BE} current limit used in this lab include one-time blowable electrical fuses, like those used in automobiles, and resettable circuit breakers, like those used in the AC electrical distribution system of modern homes. Describe both a one-time blowable **electrical fuse** (3 points) and a resettable **circuit breaker**, including what needs to happen to restore circuit operation after these devices are activated. (3 points.) (6 points total.)

    Electrical fuses have a filament in them that's designed to melt at high currents and when it melts that creates a break in the wire causing an open circuit and stopping the current flow. To restore circuit operation you would have to replace the fuse with a new one since the filament has melted away.

    Circuit breakers can have a metallic strip that's heated up at high currents until it bends which triggers a mechanical switch that opens the circuit and stops current flow or they can have a magnetic field that's generated by a high current which triggers a switch and creating a break in the circuit. For breakers you just have to flip the switch back to its normal position to restore circuit operation.

<u>Switched 12V with Current Limit Lab Grading Rubric:</u> **Submit an electronic version of a lab report to receive credit for doing this lab.** The goal of your **lab report is to provide sufficient documentation so that the lab can be repeated if necessary**. Therefore, simply add to this document to arrive at your lab report, as all of the explanatory text, procedures, and Discussion and Conclusion questions contained in this document are required for a complete lab report. So, for your lab report, **add a cover page that includes name or names, class and name of the lab. Also add in your results, and answers to the Discussion and Conclusions questions to the existing lab document**. While you are to share all **Procedure** items with your lab partner if you worked in a pair, your **Discussion and Conclusions** section is to be uniquely yours and not a copy of your lab partners. The rubric below does not need to be included in your lab report.

Lab Report Item	**Points**
Cover Page	2
Reasonable **Table 1** values with units. (1 point per entry, -0.25 points for each missing unit. Units simply added to column headings is fine.)	4
Reasonable **Table 2** values with units. (0.5 points per entry, -0.1 points for each missing unit. Units simply added to column headings is fine.)	15
Figure 4 Graph of Output Voltage versus Load Current including Figure number and caption. (5 points total, 2 points for properly plotted SW12V versus load current values, 1 point for x-axis label including units, 1 point for y-axis label including units, 1 point for title including your name/names.)	5
Discussion and Conclusions	20
Grammar and Professionalism	4
Total	50

Please give feedback on errors you find in this document.